BRE

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digest

Wind loading on buildings

Digest 436

Part 2

BS 6399-2:1997 worked examples – effective wind speeds for a site, and loads on a two-storey house

This Part is the second of a three-part Digest giving brief guidance on the use of BS 6399-2.
Part 1 gives advice and guidance on implementing BS 6399-2 and suggests certain options.
This Part demonstrates the recommended options by example calculations for the case of a two-storey timber frame house.
Part 3 gives example calculations for a further two building types: a steel portal frame building, and a 15-storey office tower surrounded by a two-storey podium.

This Digest is aimed at architects, engineers and professionals who need to know the effect of wind on buildings, and design options that minimise it.

The full title of BS 6399-2:1997 is *Loading for buildings. Code of practice for wind loads*. In this Digest we refer to it as BS 6399-2 or the Standard. It supersedes BS 6399-2:1995 which itself was a technical revision of *Loading. Wind loads*,CP3:Chapter V:Part 3:1972 (abbreviated here to CP3-V-2 or the Code); references to Code or Code of practice are to this 1972 document.

The three stages

BS 6399-2 is implemented in three distinct stages:

1 the dynamic classification: to ensure that the Standard is suitable for the structural form,
2 the design dynamic pressure for the site which is independent of the structural form of the building, and
3 the pressure coefficients and structural loads on the building.

Figures and tables in this Digest are denoted by letters (eg Figure A, Table A) to distinguish them from those in BS 6399-2. Except where specifically noted, any numbered reference to a Clause (§), Figure or Table, refers to that in BS 6399-2:1997.

BS 6399-2 is intended only for buildings that may be assumed to be static. Dynamic buildings are excluded; however the dynamic augmentation factor provided by stage 1 allows the standard to be applied to buildings that are mildly dynamic.

Stage 2 depends on the location and exposure of the site and is independent of the building, except that the shape and size of the building determines the reference heights for the design wind speeds. In this Digest, stage 2 is demonstrated for a notional site in Sheffield, and the calculations show the three options recommended in Q33 of Part 1.

Stage 3 depends on the shape and structural form of the building and gives the design loads on the structure, components and cladding of the building. This Part demonstrates the calculation of the principal structural loads for the frame panels and the retaining forces for the highest-loaded roof truss for a two-storey timber frame house.

The notional site location

For the example calculations in this Part and also Part 3 of this Digest, we shall assume the site lies in the south west outskirts of Sheffield at grid reference SK320810. This site has been chosen to illustrate the options recommended in Part 1 because it is typical of sites in inland towns.

At sites near west-facing coasts there will be less inherent conservatism, so less difference between the options. At sites near the north-west outskirts of towns or near east-facing coasts, there will be more inherent conservatism and more difference between the options.

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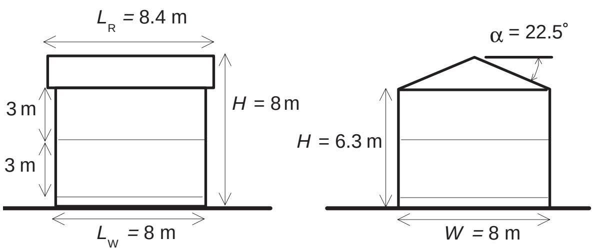

Figure A Principal dimensions of the two-storey house

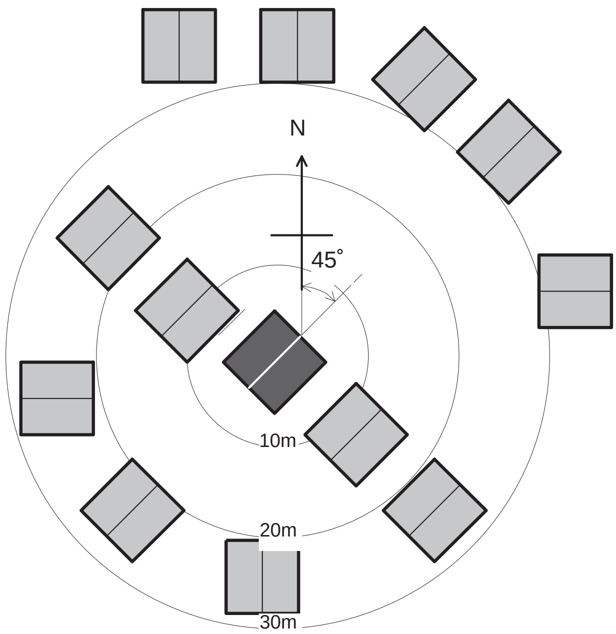

Figure B Site layout of house

The distances-from-sea and the distance-in-town should be determined as recommended in Q14 of Part 1. The relevant values for grid reference SK320810 are given in Table A from which values for each of the calculation options will be taken. The altitude of the site is 120 m above mean sea level and the site is **not** in the zone of significant topography defined in Figure 7.

The two-storey house

The example timber frame house comprises two 3 m-high timber frame storeys sitting on a 300 mm high foundation, with a duopitch roof formed from 15 timber trusses at 600 mm centres. The principal dimensions are given in Figure A. Note that the roof has a 200 mm overhang at each gable.

Stage 1: Dynamic classification

This is a test to determine whether it is appropriate to use BS 6399-2 and to obtain the value of C_r, and is demonstrated in Calculation 1.

Stage 2: Design wind speed and dynamic pressure

Notional site layout

In accordance with §1.7.2, and the distances in Table A, the site is categorised as in-town terrain.

We shall assume the house to be surrounded by similar two-storey houses. A notional layout of the immediate neighbours is shown in Figure B. The house is aligned with the ridge at 45° east of north.

The obstruction height and spacing of the neighbouring buildings should be determined as described in Q8 of Part 1. Obstruction height, H_o, is the average level of roof tops, which is the average of the ridge heights in this case (H_o = 8 m).

Values of the obstruction parameters are given in Table B.

Table A Distances-to-sea and in-town for the site at SK320810

Direction (°)	0	30	60	90	120	150	180	210	240	270	300	330
Distance to sea (km)	200	128	110	110	200	200	200	200	200	200	112	200
Distance in town (km)	7.5	12.5	9.5	3.5	2.5	1.5	1.5	3.5	2.5	2.5	1.5	3.5

Note A

The value of C_r given by the classification indicates that the house is only 1% dynamic.

Calculation 1 Dynamic classification of the two-storey house

Clause	Action		Notes
1.3.3.2	Building height above its base	H = 6.3 m	*Use height to eaves*
1.6.1	Read value of K_b from Table 1	K_b = 0.5	*When in doubt, take next larger value*
1.6.1	Using H and K_b, read C_r from Figure 3	C_r = 0.01	*If C_r > 0.1, get better value from Annex C*
			If C_r > 0.25, BS 6399-2 is not applicable
1.6.2	Check C_r < 0.25	Yes	*BS 6399 can be used*

Note B

Distances are quoted to a higher resolution than recommended in Q14 of Part 1.

Table B Obstruction parameters for the two-storey house

Direction (°)	0	30	60	90	120	150	180	210	240	270	300	330
Obstruction height (m)	8	8	8	8	8	8	8	8	8	8	8	8
Obstruction separation (m)	30	30	30	30	4	4	20	20	20	20	4	30

Option 1: Single worst case, irrespective of direction

Demonstrated in Calculation 2, this is the simplest but most conservative option in which the worst combination of parameters is taken irrespective of direction.

Note C

Ready-reckoner gives values of S_b directly, avoiding the use of S_c, S_t, T_c and T_t factors.

Calculation 2 Options 1(a) and (b) for H_r = 8 m (ridge height)

Clause	Action	Notes
2.2.1	From Figure 6, basic wind speed V_b = 22.6 m/s	*Hourly mean speed 10 m above flat open country*
1.3.3.1	From site plan, altitude of site Δ = 120 m	*Taken from OS 1:50,000 map*
2.2.2.2.1	Using Figure 7, check for significant topography = No	*Site less than halfway up hill. (But* ***is*** *significant in CP3-V-2)*
2.2.2.2	From Equation 9, altitude factor S_a = 1.12	*Topography not significant*
2.2.2.1	From Equation 8, site wind speed V_s = 25.3 m/s	*S_d, S_s and S_p all taken as unity*
1.3.3.4	Select lowest obstruction height H_o = 8 m	*Need lowest, but all buildings are same height in this case*
	Select furthest obstruction separation X_o = 30 m	*Corresponds to sector from north to east*
E.2.1	From Q10 of Part 1, displacement height H_d = $1.2H_o - 0.2\,X_o$ = 3.6 m	*Useful intermediate value defined in Annex E*
2.2.3.3	From Table A, closest distance-to-sea = 110 km	*East coast is closest, >100 km*
	From Table A, shortest distance-in-town = 1.5 km	*To SSW boundary of Sheffield*
1.7.3.1	Reference height at ridge H_r = 8 m	*Safe assumption for whole building*
1.7.3.3	From Q10 of Part 1, effective height H_e = $H_r - H_d$ = 4.4 m	*Check value is not less than 0.4 H_r*
Option 1(a): use Table 4		
2.2.3.3	From Table 4, terrain-&-building factor S_b = 1.43	*If less than 2 km in town, use country column*
2.2.3.1	From Equation 12, effective wind speed V_e = 36.3 m/s	*Now gust speed, equivalent to CP3 Class A*
2.1.2.1	From Equation 1, dynamic pressure, q_s = 808 Pa	*Gust dynamic pressure, equivalent to CP3 Class A*
Option 1(b): use Equation 29 or ready-reckoner		
3.2.3.2.3	From Table 23, factor S_c = 0.860 From Table 23, factor S_t = 0.194 From Table 24, factor T_c = 0.738 From Table 24, factor T_t = 1.655	*Tables have logarithmic steps, so logarithmic interpolation is better than linear. (Logarithmic interpolation used here)*
3.4.2.1	Standard value of factor g_t = 3.44	*Equivalent to CP3 Class A*
3.4.2	From Equation 29, terrain-&-building factor S_b = 1.34	*Equation 29 allows for actual distance-in-town*
2.2.3.1	From Equation 12, effective wind speed V_e = 33.8 m/s	*Now gust speed, equivalent to CP3 Class A*
2.1.2.1	From Equation 1, dynamic pressure q_s = 701.1 Pa	*Gust dynamic pressure, equivalent to CP3 Class A*

Note D

Clause 2.4.1.3 defines the height of walls as 'height of the wall, including any parapet or gable'. This is the eaves height for the side walls and the height of the gable peak for the gable walls.

Calculation 2 determines the design dynamic pressure, at the ridge height of the building, that is appropriate for the design of the roof and the gable walls. This is conservative for the side walls (see §1.7.3.1) for which the reference height is the height of eaves, as in Calculation 3 on page 4.

Note E

Ready-reckoner gives values of S_b directly, avoiding the use of S_c, S_t, T_c and T_t factors.

Calculation 3 Options 1(a) and (b) for H_r = 6.3 m (eaves height)

Clause	Action	Notes
1.7.3.1	Reference height at eaves H_r = 6.3 m	*Height of wall to eaves applies*
1.7.3.3	From Q10 of Part 1, effective height H_e = $H_r - H_d$ = 2.7 m	*Check value not less than 0.4H_r*
Option 1(a): use Table 4		
2.2.3.3	From Table 4, terrain-&-building factor S_b = 1.32	*Less than 2 km in town, so use country column*
2.2.3.1	From Equation 12, effective wind speed V_e = 33.5 m/s	*Now gust speed, equivalent to CP3 Class A*
2.1.2.1	From Equation 1, dynamic pressure q_s = 689.2 Pa	*Gust dynamic pressure, equivalent to CP3 Class A*
Option 1(b): use Equation 29 or ready-reckoner		
3.2.3.2.3	From Table 23, factor S_c = 0.776	*Tables have logarithmic steps, so logarithmic interpolation is better than linear. (Logarithmic interpolation used here)*
	From Table 23, factor S_t = 0.206	
	From Table 24, factor T_c = 0.669	
	From Table 24, factor T_t = 1.799	
3.4.2.1	Standard value of factor g_t = 3.44	*Equivalent to CP3 Class A*
3.4.2	From Equation 29, terrain-&-building factor S_b = 1.18	*Equation 29 allows for actual distance-in-town*
2.2.3.1	From Equation.12, effective wind speed V_e = 29.9 m/s	*Now gust speed, equivalent to CP3 Class A*
2.1.2.1	From Equation 1, dynamic pressure q_s = 547.0 Pa	*Gust dynamic pressure, equivalent to CP3 Class A*

Option 2: Four orthogonal cases, most onerous values found 45° either side of each orthogonal direction

To apply this option the orientation of the building must be known. In the example of Figure B, the ridge line is aligned 45° from north.

The resulting four orthogonal load cases are shown in Figure C, denoted by corresponding wind directions NW, NE, SE and SW. Option 2 uses the worst combination of parameters found 45° either side of each of these orthogonal directions.

To avoid unnecessary repetition, Calculation 4 determines values for only the ridge height of H_r = 8 m. The reader may like to calculate values for the eaves height of H_r = 6.3 m as an exercise.

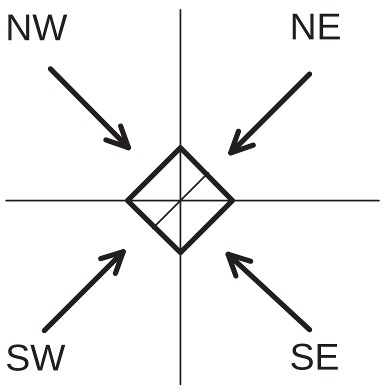

Figure C Orthogonal load cases for house

Note F

Ready-reckoner gives values of S_b directly, avoiding the use of S_c, S_t, T_c and T_t factors.

Calculation 4 Options 2(a) and (b) for H_r = 8 m (ridge height)

Clause	Action						Notes
2.2.1	From Figure 6, basic wind speed V_b = 22.6 m/s						*Hourly mean speed, 10 m above flat open country*
1.3.3.1	From site plan, altitude of site Δ = 120 m						*Take from OS 1:50,000 mapping*
2.2.2.2.1	Using Figure 7, check for significant topography = No						*Site less than halfway up hill*
2.2.2.2	From Equation 9, altitude factor S_a = 1.120						*Topography not significant*
2.1.1.2	**Orthogonal direction :**	**NE**	**SE**	**SW**	**NW**		*Range of NE includes 0°, 30°, 60° and 90°*
2.2.2.3	From Table 3, select biggest direction factor in range S_d =	0.78	0.85	1.00	0.99		*NE value is biggest of 0.78, 0.73, 0.73 and 0.74*
2.2.2.1	From Equation 8, site wind speed V_s =	19.74	21.52	25.31	25.06	m/s	*S_s and S_p taken as unity*
1.3.3.4	Select lowest obstruction height in range H_o =	8.0	8.0	8.0	8.0	m	*All sectors have two-storey buildings*
	Select furthest obstruction separation in range X_o =	30	30	20	30	m	*Selected for range from Table A*
E.2.1	From Q10 of Part 1, displacement height H_d =	3.6	3.6	5.6	3.6	m	*Defined in Annex E* $H_d = 1.2H_o - 0.2X_o$
2.2.3.3	From Table A, closest distance to sea in range =	110	110	200	112	km	*Selected for range from Table A*
	From Table A, shortest distance in town in range =	3.5	1.5	1.5	1.5	km	*Selected for range from Table A*
1.7.3.1	Reference height at ridge H_r =	8.0	8.0	8.0	8.0	m	*Safe assumption for whole building*
1.7.3.3	From Q10 of Part 1, effective height, $H_e = H_r - H_d$ =	4.4	4.4	3.2	4.4	m	*Check value not less than $0.4H_r$*
Option 2(a): use Table 4							
2.2.3.3	From Table 4, terrain-&-building factor S_b =	1.323	1.434	1.363	1.434		*When less than 2 km in town, use country column*
2.2.3.1	From Equation 12, effective wind speed V_e =	26.1	30.9	34.5	35.9	m/s	*Now gust speed, equivalent to CP3 Class A*
2.1.2.1	From Equation 1, dynamic pressure q_s =	418.1	583.7	729.5	791.9	Pa	*Gust dynamic pressure, equivalent to CP3 Class A*
Option 2(b): use Equation 29 or ready-reckoner							
3.2.3.2.3	From Table 22, factor S_c =	0.860	0.860	0.805	0.860		*Logarithmic interpolation used in Tables 22 and 23, but linear interpolation is adequate*
	From Table 22, factor S_t =	0.194	0.194	0.201	0.194		
	From Table 23, factor T_c =	0.718	0.738	0.695	0.738		
	From Table 23, factor T_t =	1.655	1.655	1.742	1.655		
3.4.2.1	Standard value of factor g_t =	3.44	3.44	3.44	3.44		*Equivalent to CP3 Class A*
2.2.3.3	From Equation 29, terrain-&-building factor S_b =	1.299	1.336	1.234	1.336		*Equation 29 allows for actual distance-in-town*
2.2.3.1	From Equation 12, effective wind speed V_e =	25.6	28.7	31.2	33.5	m/s	*Now gust speed, equivalent to CP3 Class A*
2.1.2.1	From Equation 1, dynamic pressure q_s =	403.3	506.5	598.4	687.1	Pa	*Gust dynamic pressure, equivalent to CP3 Class A*

Option 3: Twelve wind directions, taking largest dynamic pressure 45° either side of each orthogonal case

This option is the least conservative and requires the most calculations, but is very amenable to implementation by spreadsheet. If the orientation of the building is not known, the largest dynamic pressure found in all wind directions can be safely used. Each line in Calculation 5 (on page 6) is equivalent to the corresponding line in Calculation 4, except there are twelve 30°-wide ranges instead of four 90°-wide ranges. The most onerous values for each orthogonal range are selected from the calculated effective wind speeds and dynamic pressures at the end of the calculation.

Calculation 5 Options 3(a) and (b) for H_r = 8 m (ridge height)

Basic wind speed V_b =	22.6	m/s											
Altitude Δ =	120	m/s	(Check topography not significant in Figure 7)										
Altitude factor S_a =	1.12												
Direction φ =	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**deg**
Direction factor S_d =	0.78	0.73	0.73	0.74	0.73	0.80	0.85	0.93	1.00	0.99	0.91	0.82	
Site wind speed V_s =	19.74	18.48	18.48	18.73	18.48	20.25	21.52	23.54	25.31	25.06	23.03	20.76	m/s
Obstruction height H_0 =	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	m
Obstruction separation X_0 =	30	30	30	30	4	4	20	20	20	20	4	30	m
Displacement height H_d =	3.6	3.6	3.6	3.6	6.4	6.4	5.6	5.6	5.6	5.6	6.4	3.6	m
Distance-to-sea =	200	128	110	110	200	200	200	200	200	200	112	200	km
Distance-in-town =	7.5	12.5	9.5	3.5	2.5	1.5	1.5	3.5	2.5	2.5	1.5	3.5	km
Reference height H_r =	8	8	8	8	8	8	8	8	8	8	8	8	
Effective height H_e =	4.4	4.4	4.4	4.4	3.2	3.2	3.2	3.2	3.2	3.2	3.2	4.4	m
Option 3(a): use Table 4													
Terrain & building factor S_b =	1.32	1.32	1.32	1.32	1.22	1.36	1.36	1.22	1.22	1.22	1.36	1.32	
Effective wind speed V_e =	26.1	24.4	24.4	24.8	22.6	27.6	29.3	28.8	30.9	30.6	31.4	27.5	m/s
Dynamic pressure q_s =	418.1	366.2	366.2	376.3	312.5	466.9	527.1	507.2	586.5	574.8	604.1	462.0	Pa
Option 3(b): use Equation 29 or ready-reckoner													
Factor S_c =	0.860	0.860	0.860	0.860	0.805	0.805	0.805	0.805	0.805	0.805	0.805	0.860	
Factor S_t =	0.194	0.194	0.194	0.194	0.201	0.201	0.201	0.201	0.201	0.201	0.201	0.194	
Factor T_c =	0.702	0.693	0.698	0.718	0.683	0.695	0.695	0.676	0.683	0.683	0.695	0.718	
Factor T_t =	1.655	1.655	1.655	1.655	1.742	1.742	1.742	1.742	1.742	1.742	1.742	1.655	
Gust peak factor g_t =	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44	3.44	
Terrain & building factor S_b =	1.271	1.255	1.264	1.299	1.213	1.234	1.234	1.200	1.213	1.213	1.234	1.299	
Effective wind speed V_e =	25.1	23.2	23.3	24.3	22.4	25.0	26.6	28.3	30.7	30.4	28.4	27.0	m/s
Dynamic pressure q_s =	386.2	329.7	334.2	363.0	307.9	383.0	432.3	489.3	577.9	566.4	495.5	445.7	Pa
Most onerous values for orthogonal cases	**Option 3(a)**								**Option 3(b)**				
Orthogonal direction =	**NE**	**SE**	**SW**	**NW**					**NE**	**SE**	**SW**	**NW**	
Effective wind speed V_e =	26.1	29.3	30.9	31.4	m/s				25.1	26.6	30.7	30.4	m/s
Dynamic pressure q_s =	418.1	527.1	586.5	604.1	Pa				386.2	432.3	577.9	566.4	Pa

Note G
(Calculation 5)

Clause numbers and notes have been omitted to save space. Refer to the corresponding line in Calculation 4.

Comparison of options

The design dynamic pressures obtained for this site at H_r = 8 m are compared in Table C for each of the options recommended in Q33 of Part 1. As the wind loads are directly proportional to dynamic pressure, this illustrates the reductions in conservatism that can be obtained at this site. Conservatism is eliminated as we move from options 1 to 2 to 3, and as we move from (a) to (b). This particular site is typical of inland towns and we would expect to eliminate more conservatism from sites near the east coast and less from sites near the west coast.

Table C Comparison of dynamic pressure at H_r = 8 m for each option

Option	1(a)	1(b)	2(a)	2(b)	3(a)	3(b)	*Notes*
NE	808 Pa	701.1 Pa	*418.1 Pa*	***403.3 Pa***	*418.1 Pa*	*386.2 Pa*	*Not needed*
SE	808 Pa	701.1 Pa	*583.7 Pa*	***506.5 Pa***	*527.1 Pa*	*432.3 Pa*	*Not needed*
SW	808 Pa	701.1 Pa	729.5 Pa	**598.4 Pa**	586.5 Pa	577.9 Pa	*For θ = 90°*
NW	808 Pa	701.1 Pa	791.9 Pa	**687.1 Pa**	604.1 Pa	566.4 Pa	*For θ = 0°*

Owing to the symmetry of the house, we need to consider only two orthogonal directions:

- wind normal to the ridge, θ = 0°, and
- wind parallel to the ridge, θ = 90°.

Accordingly, the orthogonal cases SW and NW control the design, and the dynamic pressures (shown by italics in Table C) for the other cases are not required.

Q16 of Part 1 advises that Option 2 gives the optimum balance between conservatism and complexity, so we shall use the dynamic pressures from the §3.4.2 hybrid option 2(b) (shown in bold) for the loading calculations which follow in Stage 3.

Note H

Symmetry of the building gives two sets of pressure coefficients.

1 Wind normal to the ridge, wind angle θ = 0°, for cases NW and SE.

2 Wind parallel to the ridge, wind angle θ = 90°, for cases NE and SW.

Stage 3: Pressure coefficients and design loads

Pressure coefficients on walls

The scaling parameters for the pressure coefficients on the walls of the house are determined in Calculation 6 from the house dimensions given in Figure A.

Calculation 6 Scaling dimensions for pressure coefficients on walls of house

Clause	Wind parallel to ridge, cases NE and SW		Wind normal to ridge, cases NW and SE	
1.3.3.2	Height, $H = 8$ m	Height of gable	Height, $H = 6.3$ m	Height of eaves
1.3.4.3	Breadth, $B = 8$ m	Figure A, $B = W$	Breadth, $B = 8$ m	Figure A, $B = L_W$
1.3.4.4	Depth, $D = 8$ m	Figure A, $D = L_W$	Depth, $D = 8$ m	Figure A, $D = W$
2.2.3.2	$H = B$, one part, $H_r = 8$ m	Peak of gable	$H < B$, one part, $H_r = 6.3$ m	Eaves
2.4.1.2	Span ratio, $D/H = 1.0$	See Table 5	Span ratio, $D/H = 1.3$	See Table 5
2.4.1.3	Scaling length, $b = 8$ m	Smaller of B or $2H$	Scaling length, $b = 8$ m	Smaller of B or $2H$
2.4.1.4	Gap = 4 m	Both sides (see Table A)	Gap > 20 m	
	Gap/b = 0.5	Maximum funnelling	Gap/b > 1	Isolated

The corresponding values of pressure coefficient for each wall zone are shown in Figure D and Figure E.

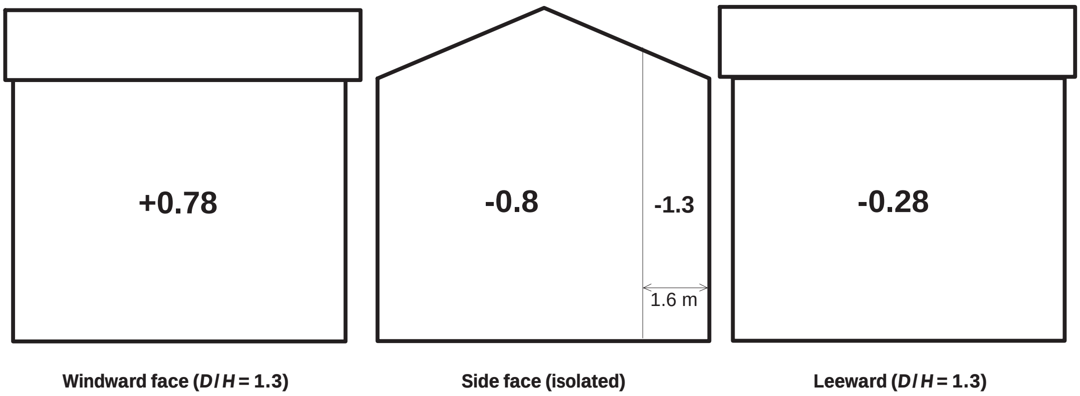

Figure D Pressure coefficients for walls of house, θ = 0° (NW and SE), from Table 5

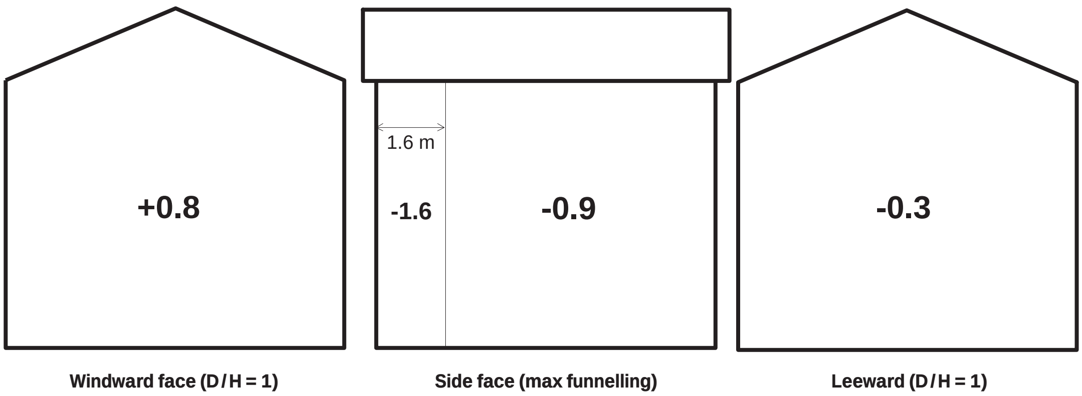

Figure E Pressure coefficients on walls of house, θ = 90° (NE and SW), from Table 5

Pressure coefficients on roof

The scaling parameters for the pressure coefficients on the roof of the house are determined in Calculation 7 (on page 8) from the house dimensions given in Figure A. The corresponding pressure coefficients for the roof are given in Figure F (on page 8).

Calculation 7 Scaling dimensions for pressure coefficients on the roof of the house

Clause	Wind parallel to ridge, cases NE and SW		Wind normal to ridge, cases NW and SE	
1.3.3.2	Height, $H = 8$ m $= H_r$	Height of ridge	Height, $H = 8$ m $= H_r$	Height of ridge
1.3.4.3	Breadth, $B = 8$ m	Figure A, $B = W$	Breadth, $B = 8.4$ m	Figure A, $B = L_R$
2.5.2.2	Scaling length, $b_W = 8$ m	Smaller of B or $2H$	Scaling length, $b_L = 8.4$ m	Smaller of B or $2H$
2.5.4.1	Pitch, $\alpha = 22.5°$, wind angle, $\theta = 90°$		Pitch, $\alpha = 22.5°$, wind angle, $\theta = 0°$	

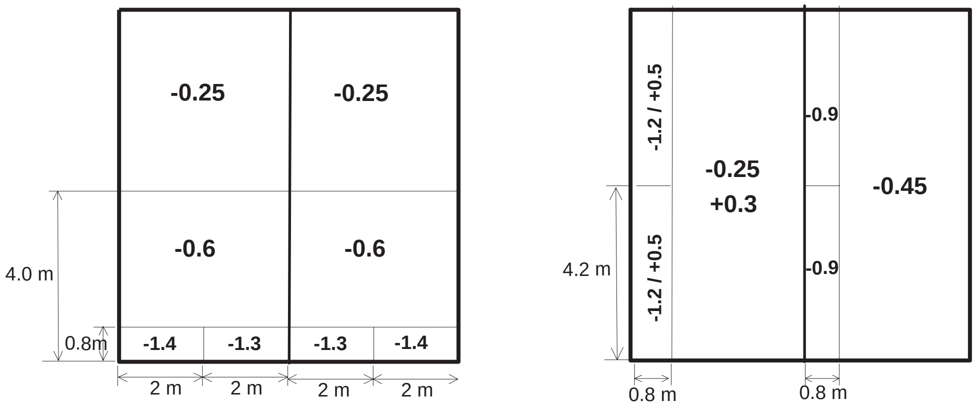

Figure F Pressure coefficients on the roof of the house (from Table 10)

Because the roof pitch of $\alpha = 22.5°$ lies in the range $+15° < \alpha < +30°$, cases NW and SE give both positive and negative values of pressure coefficient on the upwind slope of the roof (see Note 1 of Table 10). When considering the overall horizontal forces, the positive values are the more onerous. When considering uplift forces on the roof, the negative values are the more onerous. Zones B and F do not exist because of the proportions of the roof.

Racking forces in timber frame panels

To select suitable timber frame panels we need to know the horizontal shear forces at the mid-height of each panel, as shown in Figure G. The racking shear load for the lower panels P_1 is the sum of the horizontal loads on the roof or gable, the upper storey and the top half of the lower storey. The racking load for the upper panels P_2 is the sum of the horizontal loads on the roof or gable and the top half of the upper storey. Figure H shows the loaded areas (unshaded; A in equations) in elevation, together with the corresponding diagonal dimensions a.

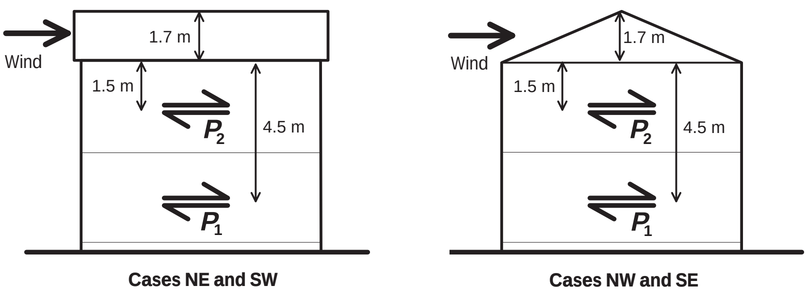

Figure G Principal racking loads for two-storey house

Note I

The loaded area A is the area of the building, in horizontal projection, above the required level for the shear force. The diagonal dimension a is the biggest diagonal a across that area.

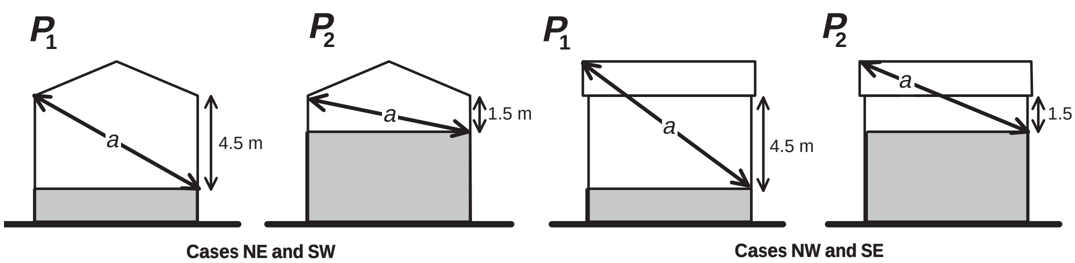

Figure H Loaded areas and diagonal dimensions for racking loads of house

Figure I shows the pressure coefficients, taken from Figures D and E, and the dynamic pressures, taken from Table C, for the dominant load cases SW and NW, with the additional dynamic pressure at eaves height for the NW load case.

The racking loads calculations are demonstrated for Case SW in Calculation 8 and for Case NW in Calculation 9.

Note J

The value of q_s = 536.1 Pa at the eaves height for Case NW is obtained by setting H_r = 6.3 m in the Option 2(b) calculation. This is left as an exercise for the reader. (See Q10 of Part 1.)

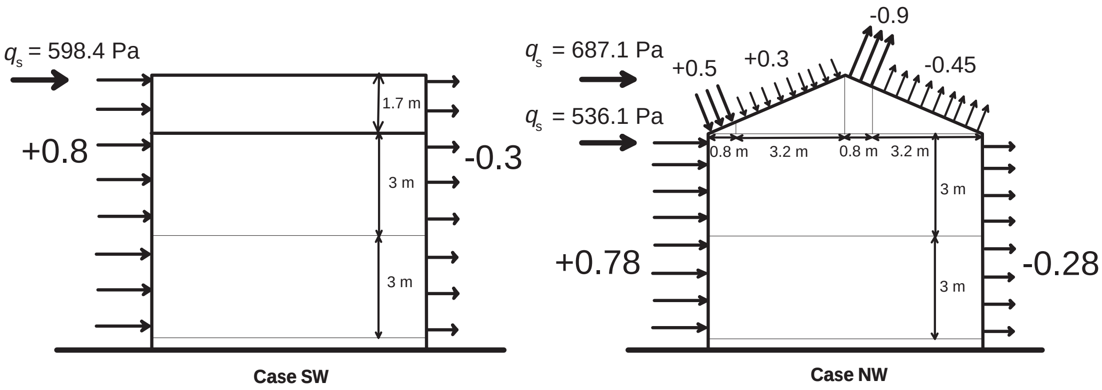

Figure I Pressure coefficients and dynamic pressures for racking of the two-storey house

Note K

When summing loads on a number of components (eg gable, top and bottom storeys), it is convenient to determine the unfactored loads on each component by taking C_a = 1; then to apply the value of C_a appropriate to the total loaded area **after** summation.

Calculation 8 Racking loads for Case SW, wind parallel to ridge

Clause	Action	Notes
2.1.3.5	Unfactored* horizontal force on gable $q_s \times (C_{p\,front} - C_{p\,rear}) \times A = 598.4 \times (0.8 + 0.3) \times 8 \times 1.7/2 = 4477$ N Unfactored* horizontal force on each storey $q_s \times (C_{p\,front} - C_{p\,rear}) \times A = 598.4 \times (0.8 + 0.3) \times 8 \times 3 = 15\,800$ N	*Apply C_a later. See Q21 of Part 1 and Note K
2.1.3.4	Diagonal dimension for P_1, $a_1 = \sqrt{(8^2 + 4.5^2)} = 9.2$ m Diagonal dimension for P_2, $a_2 = \sqrt{(8^2 + 1.5^2)} = 8.1$ m	See Figure H
	Size effect factor for P_1, $C_{a1} = 0.945$ Size effect factor for P_2, $C_{a2} = 0.956$	Figure 4, line C, site in town
2.1.3.6	Racking load $P_1 = 0.85 \times (S_{p\,front} - S_{p\,rear}) \times C_a \times (1 + C_r)$ $= 0.85 \times (4477 + 15\,800 \times 3/2) \times 0.945 \times 1.01 = 22\,858$ N Racking load $P_2 = 0.85 \times (S_{p\,front} - S_{p\,rear}) \times C_a \times (1 + C_r)$ $= 0.85 \times (4477 + 15\,800 \times 1/2) \times 0.956 \times 1.01 = 10\,156$ N	Now includes C_a size effect and C_r dynamic augmentation

Note L

Dimensions of roof zones are horizontal dimensions defined in plan. With dimensions up roof slope, divide by cos(α) for true sizes or multiply by tan(α) for vertical projection.

Calculation 9 Racking loads for Case NW, wind normal to ridge

Clause	Action	Notes
2.1.3.5	Unfactored* horizontal force on roof $q_s \times (C_{p\,front} - C_{p\,rear}) \times A$ $= 687.1 \times (0.5 \times 0.8 + 0.3 \times 3.2 + 0.9 \times 0.8 + 0.45 \times 3.2)$ $\times \tan(22.5°) \times 8.4 = 8415$ N Unfactored* horizontal force on storey $q_s \times (C_{p\,front} - C_{p\,rear}) \times A$ $= 536.1 \times (0.78 + 0.28) \times 8 \times 3 = 13\,638$ N	*Apply C_a later. See Q21 of Part 1 and Note K
2.1.3.4	Diagonal dimension for P_1, $a_1 = \sqrt{(8.2^2 + (1.7 + 4.5)^2)} = 10.3$ m Diagonal dimension for P_2, $a_2 = \sqrt{(8.2^2 + (1.7 + 1.5)^2)} = 8.8$ m	See Figure H
	Size effect factor for P_1, $C_{a1} = 0.935$ Size effect factor for P_2, $C_{a2} = 0.949$	Figure 4, line C, site in town
2.1.3.6	Racking load $P_1 = 0.85 \times (\Sigma P_{front} - \Sigma P_{rear}) \times C_a \times (1 + C_r)$ $=0.85 \times (8415 + 13\,638 \times 3/2) \times 0.935 \times 1.01 = 23\,169$ N Racking load $P_2 = 0.85 \times (\Sigma P_{front} - \Sigma P_{rear}) \times C_a \times (1 + C_r)$ $= 0.85 \times (8415 + 13\,638 \times 1/2) \times 0.949 \times 1.01 = 12\,409$ N	Now includes C_a size effect and C_r dynamic augmentation

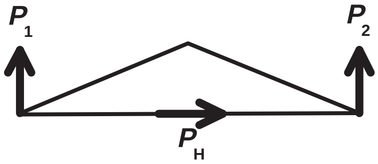

Figure J Forces on roof truss

Note M

Because pressure is a scalar, we may determine the horizontal and vertical components of load by applying the pressure to the horizontally and vertically resolved components of the surface areas, as shown in Figure K. This is exactly the same as resolving the pressure load normal to the roof surface into horizontal and vertical components.

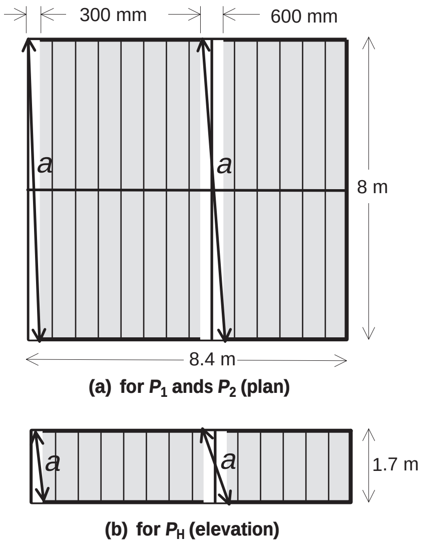

Figure K Loaded area and diagonal dimensions for trusses

Uplift forces and horizontal shear on roof truss

The forces are defined in Figure J as the uplift force on either end of the truss and the horizontal shear. For this calculation we shall assume no load sharing between trusses (worst case).

Figure K shows the tributary areas (unshaded), together with the corresponding diagonal dimensions *a* for a verge and a central truss. The simple definition of tributary area given in Q18 of Part 1 is used, defining the tributary area for a roof truss that extends for the length of the truss and halfway towards each of the adjacent trusses. The load on the truss is taken as the pressure loads on this tributary area without any load sharing between trusses. While this is a convenient practice, it is not strictly accurate when the loading is non-uniform; ie when there is a change of zone within the tributary area.

Internal pressure

The internal pressure of the upper storey acts on the underside of each truss. The calculations assume that the gable walls are permeable (ie they have opening windows and doors) and that the side walls are impermeable.

Along each verge, the pressure acting on the soffit of the 200 mm roof overhang is taken to be the pressure on the adjacent wall (§2.5.8).

Case SW, wind parallel to ridge

For wind parallel to the ridge, the verge truss lies in the edge zones A and B but has half the loaded area of the other trusses. The next truss lies partly in the A and B zones and partly in the C zone, and has the full loaded area. The other trusses lie in the C or D zones. The critical, highest loaded truss will be either the verge or the next truss. By symmetry, P_1 and P_2 are equal to the uplift on half the width of the roof and P_H is zero. Values of P_1 and P_2 for the SW case are derived in Calculation 10.

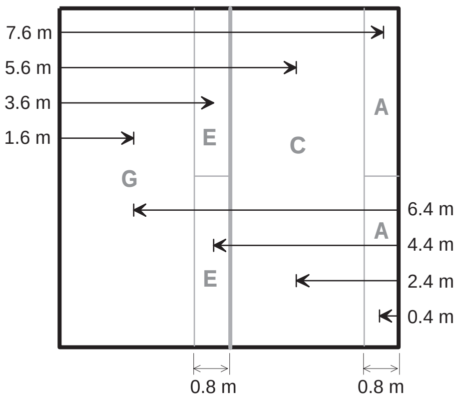

Figure L Moment arms from eaves for zones

Case NW, wind normal to ridge

For wind normal to the ridge, all trusses are loaded identically, apart for the verge trusses which have a half-size tributary area and a 200 mm overhang. From the pressure coefficients for the upwind slope, shown in Figure F, the negative values are the most onerous for uplift forces P_1 and P_2 while the positive values are the most onerous for the horizontal shear, P_H. The values of P_1 and P_2 are found by taking moments around each eaves. Figure L shows the moment arm from either eaves for each of the external pressure coefficient zones. The value of P_H is found by resolving the horizontal components of the zone areas. Values of P_1, P_2 and P_H for the NW case are derived in Calculation 11.

Calculation 10 Uplift forces on verge, next and middle trusses for Case SW

Clause	Action			Notes
Internal pressures				
2.6.1.1	From Table 16, internal pressure coefficient C_{pi} = +0.2			*Wind normal to permeable face*
	From Equation 13, diagonal dimension $a = 10 \times \sqrt[3]{(\text{volume of storey})} = 10 \times \sqrt[3]{(8 \times 8 \times 3)}$ = 57.7 m			
	From Figure 4, size effect factor C_a = 0.778			**Apply C_a later. See Q21 of Part 1 and Note K*
2.1.3.2	Unfactored* internal pressure $p_i = q_s \times C_{pi} = 598.4 \times 0.2$ = 120 Pa			
External pressures				
2.1.3.1	Unfactored* external pressures $p_e = q_s \times C_{pe}$			
	Zone A external pressure $p_{eA} = 598.4 \times (–1.4)$ = –838 Pa			
	Zone B external pressure $p_{eB} = 598.4 \times (–1.3)$ = –778 Pa			**Apply C_a later. See Q21 of Part 1 and Note K*
	Zone C external pressure $p_{eC} = 598.4 \times (–0.6)$ = –359 Pa			
2.5.8.2	Verge soffit external pressure $p_{eS} = 598.4 \times (+0.8)$ = +479 Pa			
		Verge truss	**Other trusses**	
2.1.3.4	Diagonal dimension, for P_1 & P_2, a =	$\sqrt{(8^2 + 0.3^2)}$ = 8.0 m	$\sqrt{(8^2 + (0.6)^2)}$ = 8.0 m	
	Size effect factor, for P_1 & P_2, C_a =	0.957	0.957	

Resolved areas for P_1, P_2	**Verge truss**	**Next truss**	**C-zone truss**
Zone A, A_A =	$0.3 \times 2 = 0.6$ m^2	$(0.8 – 0.3) \times 2 = 1.0$ m^2	0 m^2
Zone B, A_B =	$0.3 \times 2 = 0.6$ m^2	$(0.8 – 0.3) \times 2 = 1.0$ m^2	0 m^2
Zone C, A_C =	0 m^2	$(0.6 – 0.8 + 0.3) \times 4 = 0.40$ m^2	2.4 m^2
Internal area A_i =	$0.1 \times 4 = 0.4$ m^2	$0.6 \times 4 = 2.40$ m^2	2.4 m^2
Soffit area A_S =	$0.2 \times 4 = 0.8$ m^2	0 m^2	0 m^2

Forces

Clause	Action			Notes
2.1.3.5	$P_1 = P_2 = p_i \times A_i \times C_a – (p_{eA} \times A_A + p_{eB} \times A_B + p_{eC} \times A_C – p_{eS} \times A_S) \times C_a$			*Half total uplift*
	Verge truss	**Next truss**	**C-zone truss**	
	$P_1 = P_2 = 1332$ N	$P_1 = P_2 = 1908$ N	$P_1 = P_2 = 1048$ N	

Calculation 11 Uplift forces and horizontal shear on middle trusses for Case NW

Clause	Action		Notes
Internal pressures			
2.6.1.1	From Table 16, internal pressure coefficient C_{pi} = –0.3		*Wind normal to permeable face*
	From Equation 13, diagonal dimension $a = 10 \times \sqrt[3]{(\text{volume of storey})} = 10 \times \sqrt[3]{(8 \times 8 \times 3)}$ = 57.7 m		
	From Figure 4, size effect factor C_a = 0.778		**Apply C_a later. See Q21 of Part 1 and Note K*
2.1.3.2	Unfactored* internal pressure $p_i = q_s \times C_{pi} = 687.1 \times (–0.3)$ = –206 Pa		
External pressures			
2.1.3.4	Diagonal dimension, for P_1 & P_2, a =	$\sqrt{(8^2 + 0.3^2)}$ = 8.0 m	*See Figure C of Part 1*
	for P_H, a =	$\sqrt{(1.7^2 + 0.3^2)}$ = 1.7 m	
	Size effect factor*, for P_1 & P_2,	C_a = 0.957	**Apply C_a later. See Q21 of Part 1 and Note K*
	for P_H,	C_a = 1.00	

Clause	Action		
2.1.3.1	Unfactored* external pressures $p_e = q_s \times C_{pe}$		
		for uplift	**for shear**
	Zone A pressure p_{eA} =	$687.1 \times (–1.2) = –825$ Pa	$687.1 \times 0.5 = 344$ Pa
	Zone C pressure p_{eC} =	$687.1 \times (–0.25) = –172$ Pa	$687.1 \times 0.3 = 206$ Pa
	Zone E pressure p_{eE} =	$687.1 \times (–0.9) = –618$ Pa	$687.1 \times (–0.9) = –618$ Pa
	Zone G pressure p_{eG} =	$687.1 \times (–0.45) = –309$ Pa	$687.1 \times (–0.45) = –309$ Pa

Resolved areas for P_1, P_2 and P_H	**for uplift**	**for shear**
Zone A area A_A =	$0.6 \times 0.8 = 0.48$ m^2	$0.6 \times 0.8 \times \tan(\alpha) = 0.199$ m^2
Zone C area A_C =	$0.6 \times 3.2 = 1.92$ m^2	$0.6 \times 3.2 \times \tan(\alpha) = 0.795$ m^2
Zone E area A_E =	$0.6 \times 0.8 = 0.48$ m^2	$0.6 \times 0.8 \times \tan(\alpha) = 0.199$ m^2
Zone G area A_G =	$0.6 \times 3.2 = 1.92$ m^2	$0.6 \times 3.2 \times \tan(\alpha) = 0.795$ m^2

Forces

Clause	Action	Notes
2.1.3.5	Windward uplift force	*By taking moments around downwind eaves*
	$P_1 = (p_i \times A \times 4 \times C_a – (p_{eA} \times A_A \times 7.6 + p_{eC} \times A_C \times 5.6 + p_{eE} \times A_E \times 3.6 + p_{eG} \times A_G \times 1.6) \times C_a)/8 = 437$ N	
	Leeward uplift force	*By taking moments around upwind eaves*
	$P_2 = (p_i \times A \times 4 \times C_a – (p_{eA} \times A_A \times 0.4 + p_{eC} \times A_C \times 2.4 + p_{eE} \times A_E \times 4.4 + p_{eG} \times A_G \times 6.4) \times C_a)/8 = 339$ N	
2.1.3.6	Horizontal shear force	*By Equation 7. See Figure C of Part 1*
	$P_H = 0.85 \times (p_{eA} \times A_A + p_{eC} \times A_C + p_{eE} \times A_E + p_{eG} \times A_G) \times C_a \times (1 + C_r) = 516$ N	

The uplift forces depend on the internal pressure coefficient. In this example the gable walls were permeable and the side walls were impermeable, so the reference height for internal pressure was the height of the gable wall (to the ridge). When the side walls are permeable and the gable walls are impermeable, the reference height for internal pressure will be the height of the side wall (to eaves). This leaves the question of the reference height when all walls are permeable – as the internal pressure is set by the average flow of wind in and out of the distributed porosity, it is reasonable to take the average height of all the porous walls. When there is a dominant opening, the reference height for internal pressure will be the height of the wall that contains the dominant opening.

The range of possible values of uplift forces on the highest-loaded truss (the truss next to the verge truss) of the example building is given in Table D.

Note N

The values from the calculations are shown in bold. Verifying the other values is left as an exercise for the reader.

Note O

For this example building we find that the critical uplift forces occur for wind parallel to the ridge, even though this corresponds to the lower dynamic pressure. This observation is typical.

Table D Truss uplift forces over possible range of internal pressure

Highest-loaded truss		Case SW	Case NW	
	(Dynamic pressure q_s)	(589 Pa)	(687 Pa)	(687 Pa)
	C_{pi}	$P_1 = P_2$	P_1	P_2
Wind normal to impermeable face	–0.3	1349 N	**437 N**	**339 N**
Wind normal to permeable face	+0.2	**1908 N**	1079 N	921 N
2:1 dominant opening in windward face	+0.6	2355 N	1592 N	1495 N
3:1 dominant opening in windward face	+0.72	2489 N	1747 N	1649 N

Asymmetric loads

Clause 2.1.3.7 requires 100% of the loads where the contribution is positive (adverse) and 60% of the loads where the contribution is negative (beneficial). In the examples shown in Calculations 10 and 11, the contributions from external pressures to P_1, P_2 and P_H are positive (adverse) and the clause has no effect.

However, if the roof pitch were less than 15°, Table 10 gives only negative values for the pressure coefficients in the windward roof zones A, B and C with wind normal to the ridge. In this case, their contribution to the racking loads and the horizontal shear force on the roof truss P_H would be negative (beneficial) and should be factored by 60%. Similarly, the pressure coefficients on the downwind slope of troughed (negative pitch) roofs are always negative and their contribution to P_H would be negative (beneficial) and should also be factored by 60%.
(See Q24 of Part 1.)

Concluding comments

The worked examples in Parts 2 and 3 of this Digest illustrate much of the guidance given in Part 1 and demonstrate the steps involved in implementing BS 6399-2 for various elements of typical structures. The examples have been chosen to illustrate as many aspects as possible within the space available, but are not complete.

Although laid out as manual calculations, the examples were produced using spreadsheets that gave exact solutions to the methods used by BS 6399-2. It is not possible for manual calculations to reproduce these values exactly, for several reasons.

- The values of the S-factors in the BS 6399-2 tables are only accurate to 2%.
- Values interpolated from these tables will depend on whether effective height is interpolated before or after distance-from-sea or in-town and whether interpolation is made on a linear or logarithmic scale.
- Using values rounded to three significant figures will accumulate round-off errors.

An example of the effects of different averaging schemes can be found in the *Concluding comments* of Part 3.

Check calculations of the examples made manually should be considered successful if the effective wind speed V_e is within 0.2 m/s and the dynamic pressure, surface pressure or load is within 5% of the example values.

This particular choice of examples does not imply that explicit calculations are required for those elements that are permitted to be sized using the prescriptive methods given in Approved Document A to the Building Regulations and in BS 8103.

Publications cited in this Part will be found under *Other references* in Part 1.

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